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INVESTIGATION OF THE VISUAL BOUNDARY FOR IMMEDIATE PERCEPTION OF VERTICAL RATE OF DESCENT

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INVESTIGATION OF THE VISUAL BOUNDARY FOR IMMEDIATE PERCEPTION OF VERTICAL RATE OF DESCENT

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SUMMARY

Optical projection equipment was used to determine the threshold of immediate perception of visual angular rates. The threshold is defined as the minimum angular rate that can be detected visually with a high degree of probability in 2 seconds. A brief analytical treatment shows the relationship of visual angular rate to closure speed or rate of vertical descent.

Application of the data was made by means of the analysis to encompass ranges of speed and distance that might be encountered, for example, in an emergency vertical landing from a straight-in lunar approach. The results indicate that a human pilot has adequate visual ability to control a landing, even for this case of extreme closure velocity, if a reasonable braking thrust and adequate fuel supply are available.

INTRODUCTION

One of the questions arising in the planning for future manned lunar landings concerns the capabilities of a pilot to make final corrections required to land a rocket vehicle on the moon's surface. For the lunar landing, judgment of vertical velocity has fundamental similarity to the necessary ability displayed by a helicopter pilot in making a vertical landing. However, in the case of the helicopter landing, small distances and velocities are involved, whereas the lunar landing deceleration might, under emergency conditions, encompass much larger distances and velocities with commensurate fuel use. Therefore, it is desirable to determine human visual capability to perform this more difficult task.

In order to obtain a measure of visual capability (beyond the range of present experience) an investigation was made to determine the threshold of perception of rates of change of visual angle for various initial angles. The threshold is defined as the minimum angular rate that can be detected visually with a high degree of probability in 2 seconds. The ranges covered in the study were determined from an analysis of the conditions that might occur as surface features appear to grow in a vertical descent.

Since surface features may be unfamiliar, the optical projections used in the investigation were designed so that no dependence had to be placed on familiar features of known size and shape.

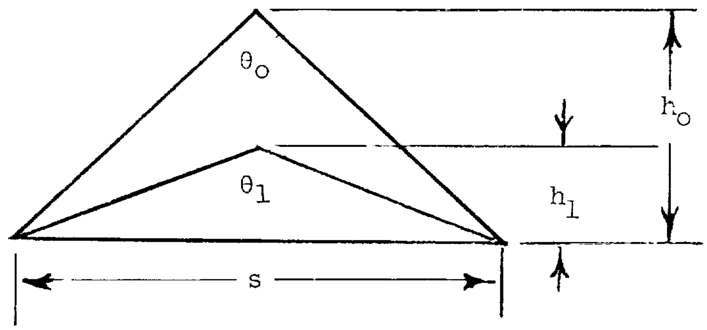
SYMBOLS

h	distance perpendicular to reference plane, ft
$\dot{h}$	velocity normal to plane, ft/sec
$\dot{h}_{min}$	threshold perception of velocity, ft/sec
s	distance on the reference plane between features which are equally spaced from the perpendicular line of sight, ft
Δt_{max}	maximum image-retention time of the eye, sec
θ	total visual angle which is subtended by the reference base-line distance s, radians unless otherwise indicated
$\Delta\theta_{min}$	angular resolution of the eye, radians
$\dot{\theta}$	rate of change of visual angle, radians/sec
$\dot{\theta}_{min}$	threshold perception of visual angular rate, radians/sec

ANALYSIS OF THE VISUAL ASPECTS OF A VERTICAL DESCENT

In order to relate visual-angle projection tests to the real case of perception of velocity, a brief analysis was made with some effort directed toward estimating the range of parameters of the tests. Because the investigation was motivated by the lunar landing problem, judgment of height was not considered a part of the problem. Height judgment is dependent on previous experience with familiar objects and for this reason is assumed to be unreliable in the presence of unknown surface conditions that might occur in any planetary landing.

Human judgment of speed (or vertical velocity) relative to a two-dimensional object is based on rate of change of the subtended visual angle. As can be seen in the following sketch,



a descent from height h_o to height h_1 will result in an increase of the visual angle from θ_o to θ_1 when an object of size s on the ground is seen. The visual reference distance s may be the size of a single object such as a boulder or it may be the distance between two objects. In the case of a descent above a reference circle or crater, the increase in visual angle would be seen as an apparent growth in diameter.

The relation between height, size of object, and subtended visual angle is

$$\tan\frac{\theta}{2} = \frac{s}{2h} \tag{1}$$

The threshold of perception of relative velocity is related to the threshold of detecting visual-angle rate. The relationship, obtained by differentiating equation (1) with respect to time, is

$$\frac{\dot{h}_{min}}{h} = -\dot{\theta}_{min}\left(\frac{1 + \tan^2\frac{\theta}{2}}{2\tan\frac{\theta}{2}}\right) \tag{2}$$

and can also be expressed

$$\dot{h}_{min} = -\dot{\theta}_{min}\left(\frac{h^2}{s} + \frac{s}{4}\right) \tag{3}$$

by substituting equation (1) in equation (2). If $\dot{\theta}_{min}$ is a constant and has no dependence on visual angle, then for the case of a single reference object, the most sensitive velocity cue will be at impact with the surface. When the view is unobstructed, however, distinctive terrain features may be seen over a wide range of visual angles. In this case, it is necessary to find the object size at a given height that will minimize the vertical velocity at the threshold; this is done by differentiating equation (3) with respect to s, holding $\dot{\theta}_{min}$ and h constant, to give

$$\frac{d\dot{h}_{min}}{ds} = -\dot{\theta}_{min}\left(\frac{-h^2}{s^2} + \frac{1}{4}\right) = 0 \tag{4}$$

and thus

$$h = \frac{s}{2} \tag{5}$$

The maximum sensitivity to velocity would therefore be provided by terrain features on a 90° visual cone. This angle, for example, might be put to the best use with a photoelectric cell for detecting velocity in an automatic landing device. However, for human control, it is the product on the right side of equation (2) that must be minimized ($\dot{\theta}_{min}$ cannot be assumed a constant with no dependence on θ) and, therefore, measurements are necessary to determine variations in the threshold of the angular-velocity perception of the eye over a range of visual angles.

MEASUREMENTS OF VELOCITY PERCEPTION

Simulation Apparatus

Since relative velocity sensation is related to rate of change of the visual angle, a simple motion projection apparatus was necessary to provide controlled and measured angular velocities. A schematic illustration of the test equipment is shown in figure 1. The tests were conducted in a dark room with vertical lines projected by a point source of light shining through two clear lines in an opaque mask. In all tests the light projected was bright and represented velocity judgment for terrain in sharp contrast. The point source of light was driven in or out relative to the mask by a controllable electric motor so that an operator could select different rates of horizontal motion of the two projected vertical light lines. For increasing visual angle the lines were driven apart and, conversely, for decreasing visual angle the line images were driven closer together. In addition to the mask with two vertical lines, a mask with 10 equally spaced concentric circles was used.

Test Methods

The tests were made in two phases. Two subjects, or observers, with normal vision took part in the tests. In the first phase, visual perception of angular velocity was determined by the motion of the projected vertical lines at a particular visual angle, with only a small range of cone angles covered by the lines. In the second phase of the tests, simulation of relative velocity with respect to features covering a large range of visual angle was made by projecting the growth and reduction of concentric circles.

The observers in the tests were seated at a distance from the screen with the vertical lines appearing at a particular visual angle for the initial-phase tests. The second-phase tests were made with the distance from the screen representing a scale range from the pattern of concentric circles. The visual angles at which the tests were made and the distances of the observers' eyes from the

images are as follows:

Light pattern	Visual angle, deg	Distance from observer to image, ft
Vertical lines	11	53
	41	15
	68	9
	128	17
Concentric circles	0 to 103	13

The total change in angle required for each test was small.

To start the tests, the motor operator quickly accelerated the motor to a constant speed and signaled the start by voice command. The subject replied, as quickly as possible, with his decision of direction of travel. The time delay for the reply was measured and angular rates were determined by timing the image movement on the screen.

RESULTS AND DISCUSSION

Angular-Rate Perception

The time necessary for the observers to discriminate the direction of angular motion and to reply is shown in figure 2, plotted as a function of angular velocity in radians per second. In the plots and in the following discussions, angular rates for both increasing and decreasing angle are treated as positive. The results are shown for two observers and, as indicated in the preceding table, were made at visual angles of 11°, 41°, 68°, and 128°.

Characteristically, the reply time quickly approaches a minimum as angular velocity exceeds a threshold region of sensation. At rates below the threshold, immediate perception is no longer possible and the direction of motion can only be sensed by noting angle changes over a greatly increased period of time. Boundaries of reply time for each direction of motion are shown on the plots indicating the maximum time that would rarely be exceeded. The boundaries for closure velocity (increasing angle) and departure velocity (decreasing angle) are appreciably different and both observers noticed and commented on the difference.

The data of figure 2 are summarized in figure 3 to show the threshold of immediate angular-velocity perception $\dot{\theta}_{min}$ as a function of the visual angle θ. The threshold is chosen as the value of $\dot{\theta}$ for which the reply time indicated by the boundary line was 2 seconds. Considering the time delay inherent in the test procedure, this reply time is believed to represent a conservative estimate of the boundary of immediate perception. Visual performance better than this limit can be relied on in a large percentage of trials. The data indicate a marked increase

of the angular rate necessary for quick perception, as the subtended visual angle θ increases from 11° to 128°. This increase may be due to reduced sensitivity as the edges of the retina are approached but may also be caused by the increased separation of the images reducing the ability to use a feature on one side of the center as a reference for judging motion on the other side of the field of view. Observer A showed greater sensitivity for immediate perception of angular-velocity rates than did observer B over most of the visual-angle range. Individual differences in performance result in a considerable difference in the plot of the threshold variation with angle. Observer B apparently had about the same sensitivity as observer A only at a visual cone angle of about 40° and lost sensitivity more rapidly than observer A as the visual angle increased. At the boundary for immediate perception there is no appreciable difference for increasing or decreasing angular rates, although there is a marked difference in the required reply time at rates less than the threshold.

Velocity Perception

The data presented in the previous figures concern only angular-rate perception at several different visual angles. These data can be applied to the relation of velocity, height, angular rate, and visual angle expressed in equation (2) to find the boundary for immediate perception of velocity as a function of the visual angle. The results of applying the data in this manner are shown in figure 4.

The plots in figure 4 indicate that observer A had greater visual sensitivity to velocity perception than observer B and that this visual ability of observer A was present over a greater range of visual angle than for observer B. The minimum point on the curve for observer A is at $\frac{\dot{h}_{min}}{h} = 0.013$ and for observer B is at $\frac{\dot{h}_{min}}{h} = 0.016$.

Although the treatment of the data in figure 4 is used to determine the boundary for rapid detection of velocity, the data are individual measurements made at several different visual angles. Perception tests were therefore made to give the observer a view with a number of objects covering a range of visual angles of about 103°. A pattern of 10 equally spaced concentric circles was projected to provide a field of view of a number of well-lighted circles with good contrast. The data from these tests are plotted in figure 5 and show good agreement with the previous results obtained by using the data collected from tests for each of several visual angles.

Logical application of well-established thresholds of vision capabilities yields a value that agrees reasonably well with the experimental results. For example, velocity sensation appears to depend upon continuous comparison of the changing sizes of images. It is reasonable to believe that the threshold perception of velocity is dependent on the minimum angular resolution and maximum image-retention time of the eye. The resolution of the eye, for ideal conditions of lighting and contrast, has been found to be about 1 minute of arc (ref. 1). An estimate of maximum image-retention time can be derived from the fact that movies

begin to flicker as projection speed is reduced to about 16 frames per second. An estimate of threshold perception of angular rate is then

$$\dot{\theta}_{min} = \frac{\Delta\theta_{min}}{\Delta t_{max}} \approx \frac{0.0003 \text{ radian}}{0.06 \text{ second}}$$

for each side of the field of view. For the total subtended visual angle this threshold estimate must be doubled and therefore

$$\dot{\theta}_{min} \approx 0.01 \text{ radian/second}$$

This estimated value agrees reasonably well with the experimental results for both observers near the visual angle of 40° (see fig. 3), and this cone angle is in the retina area that seems to contribute the greatest sensitivity to velocity perception. Thus the results obtained are consistent with known visual ability.

An additional verification of the experimental results was obtained near an altitude of 3,000 feet in flight observations from a descending helicopter. Vertical descent velocities less than 1,000 feet per minute were discernible by observer B. The corresponding value of $\dot{h}/h$ is 0.006, indicating that the boundary value chosen from the projection tests is a conservative estimate of visual performance.

APPLICATION TO LUNAR LANDING

The velocity perception ability of observer B was used to determine the point on an assumed vertical-approach path to the moon at which velocity is recognized very rapidly. The point is shown in figure 6 as the crossing of the visual-perception boundary and the assumed approach velocity and altitude variation. The dashed line indicates that a constant deceleration of 64.4 feet per second per second will enable a landing to be made from the point of velocity detection. This deceleration, however, would probably be applied earlier in most cases since the visual-perception boundary chosen is believed to represent a conservative estimate of human ability. If thrust were applied earlier or a greater braking deceleration were available, a landing could probably be made with several periods of alternate retrofire and free fall, with the operator using the visual-perception boundary as a reference for control. This method of thrust control might be useful as an emergency operation if sufficient fuel is available, but would probably not be planned as an operational procedure because of inefficient use of fuel.

CONCLUDING REMARKS

Optical projection equipment was used to determine a boundary of human perception of visual angular rates. The boundary established was an approximate lower threshold of perception of angular rate with a high level of reliability for correctly recognizing the direction of motion. A brief analysis was made to determine the relationship of visual angular rate with velocity of closure or departure. The tests indicate a conservative estimate of the boundary as compared with flight observations obtained in a descending helicopter.

Application of the results was made by means of the analysis to encompass ranges of speed and distance that could be encountered in a vertical landing from a straight-in lunar approach. The results indicate that a human operator has sufficient perception of closure for braking to a safe landing if reasonable thrust is available and enough fuel is provided to allow for an inefficient landing technique.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., October 1, 1962.

REFERENCE

1. Institute for Applied Experimental Psychology, Tufts College: Handbook of Human Engineering Data. Second ed. (rev.), Human Eng. Rep. SDC 199-1-2a (Nav Exos P-643), Naval Res., Nov. 1, 1952.

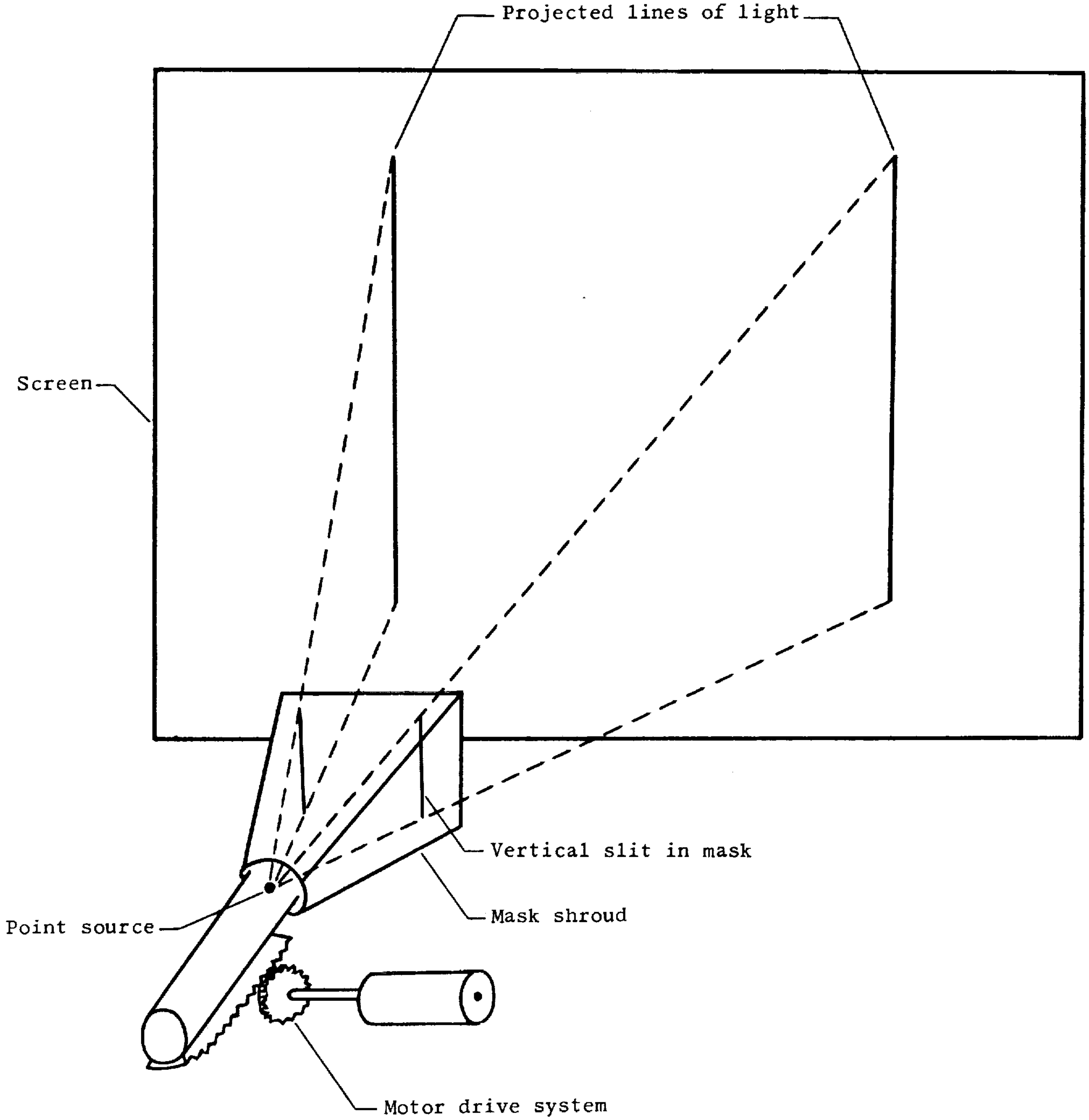
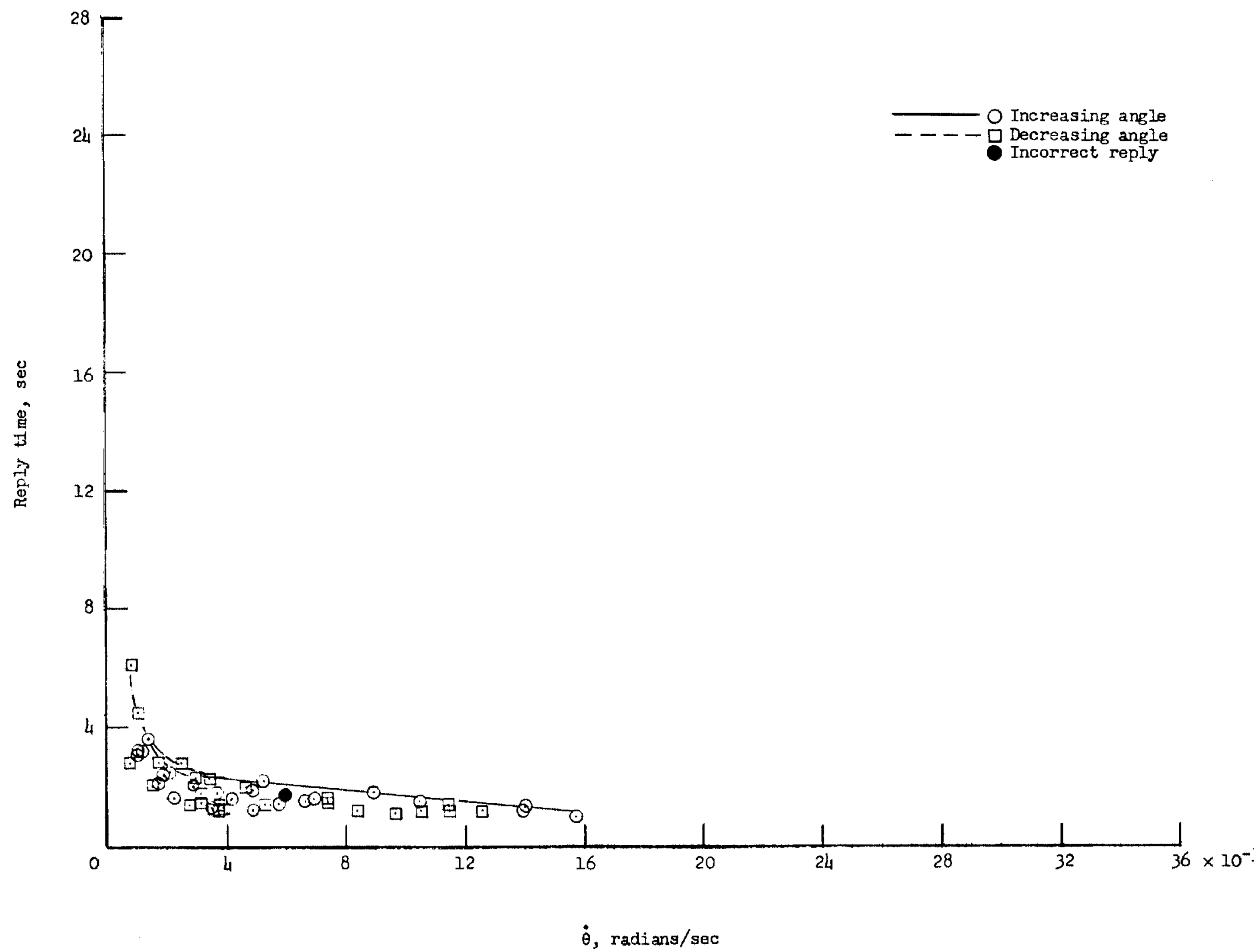
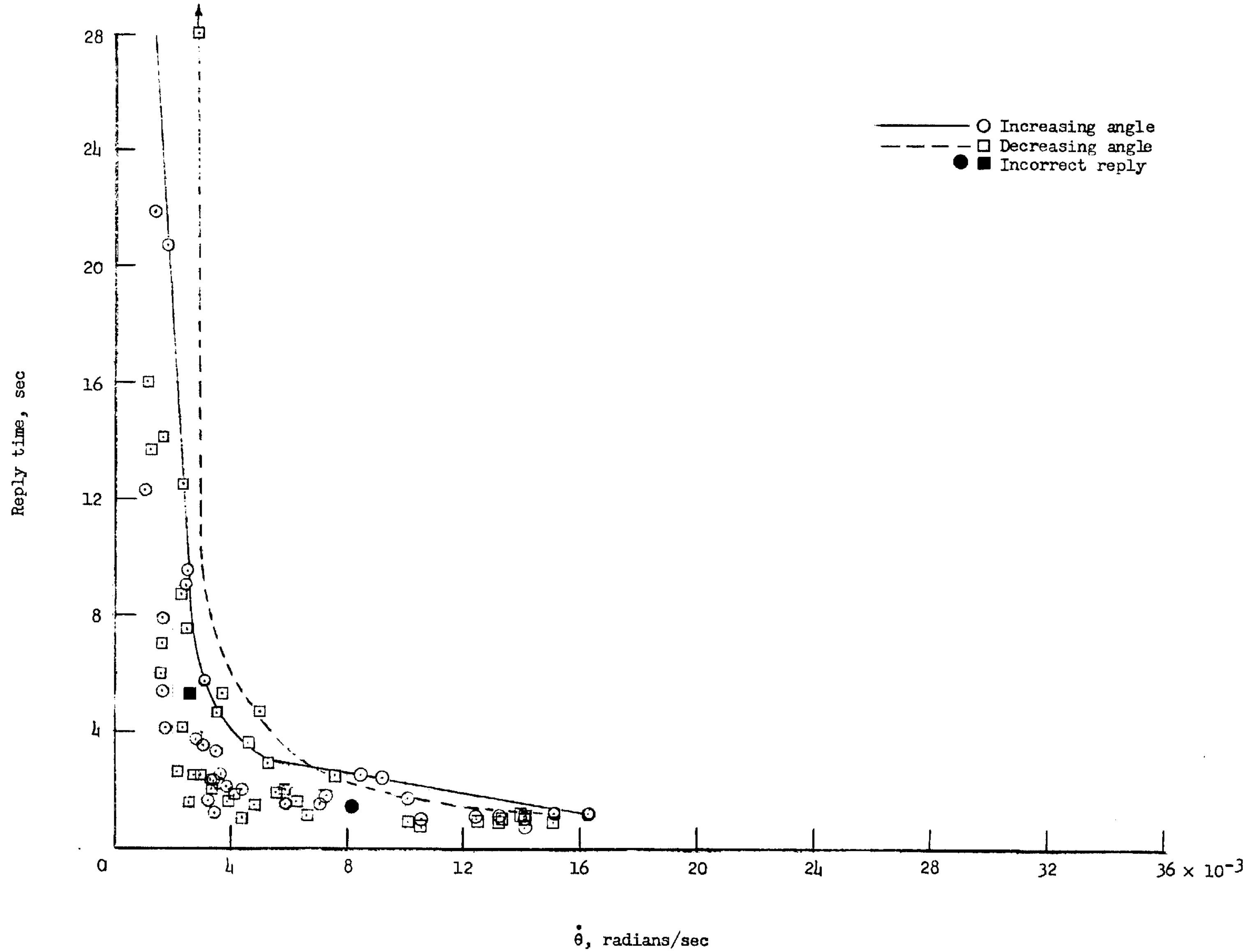


Figure 1.- Schematic sketch of motion projector.



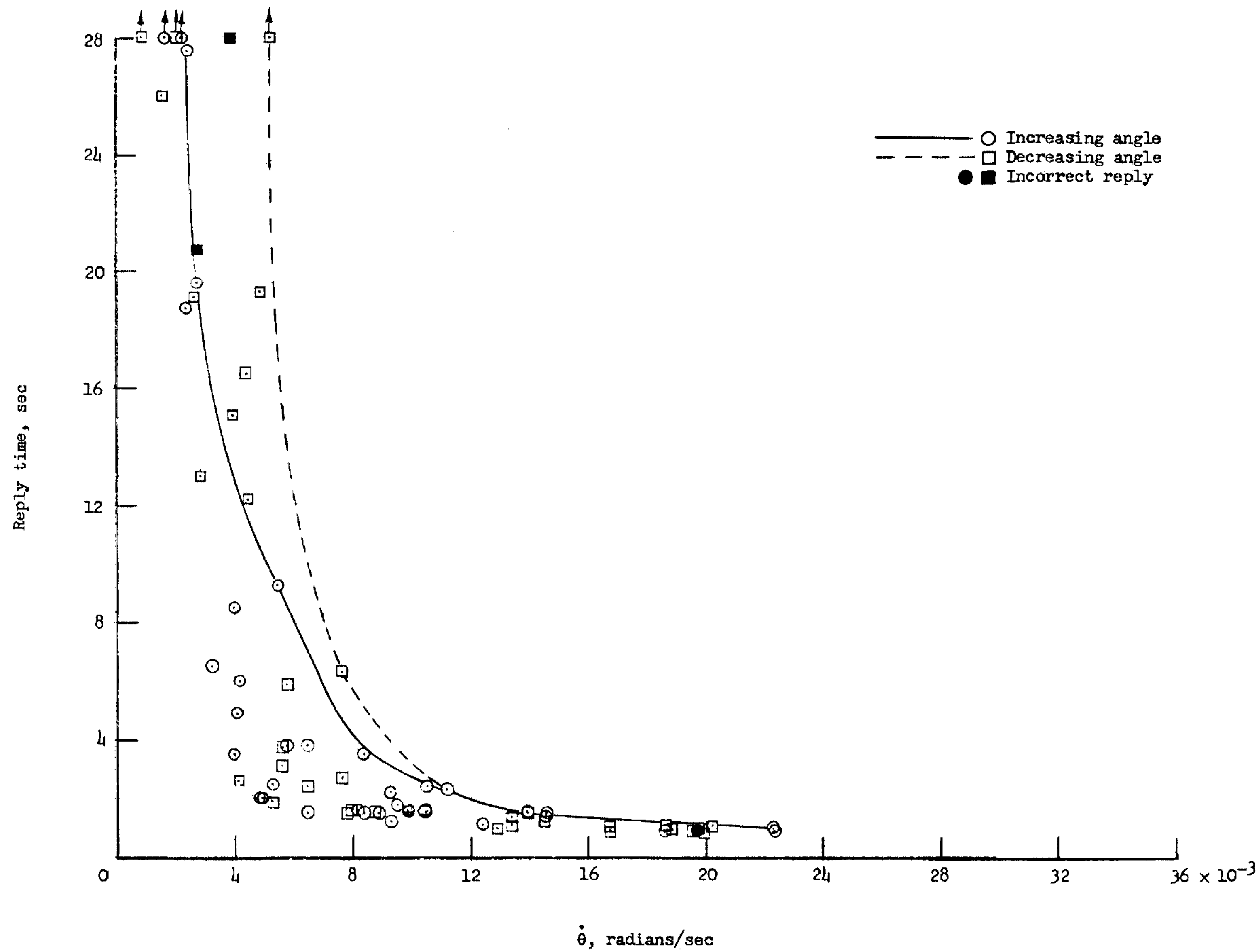
(a) Observer A. $\theta = 11^{\circ}$.

Figure 2.- Time necessary for direction decision and reply at various rates of increasing and decreasing visual angle. Curves represent boundaries of reply time that would rarely be exceeded.



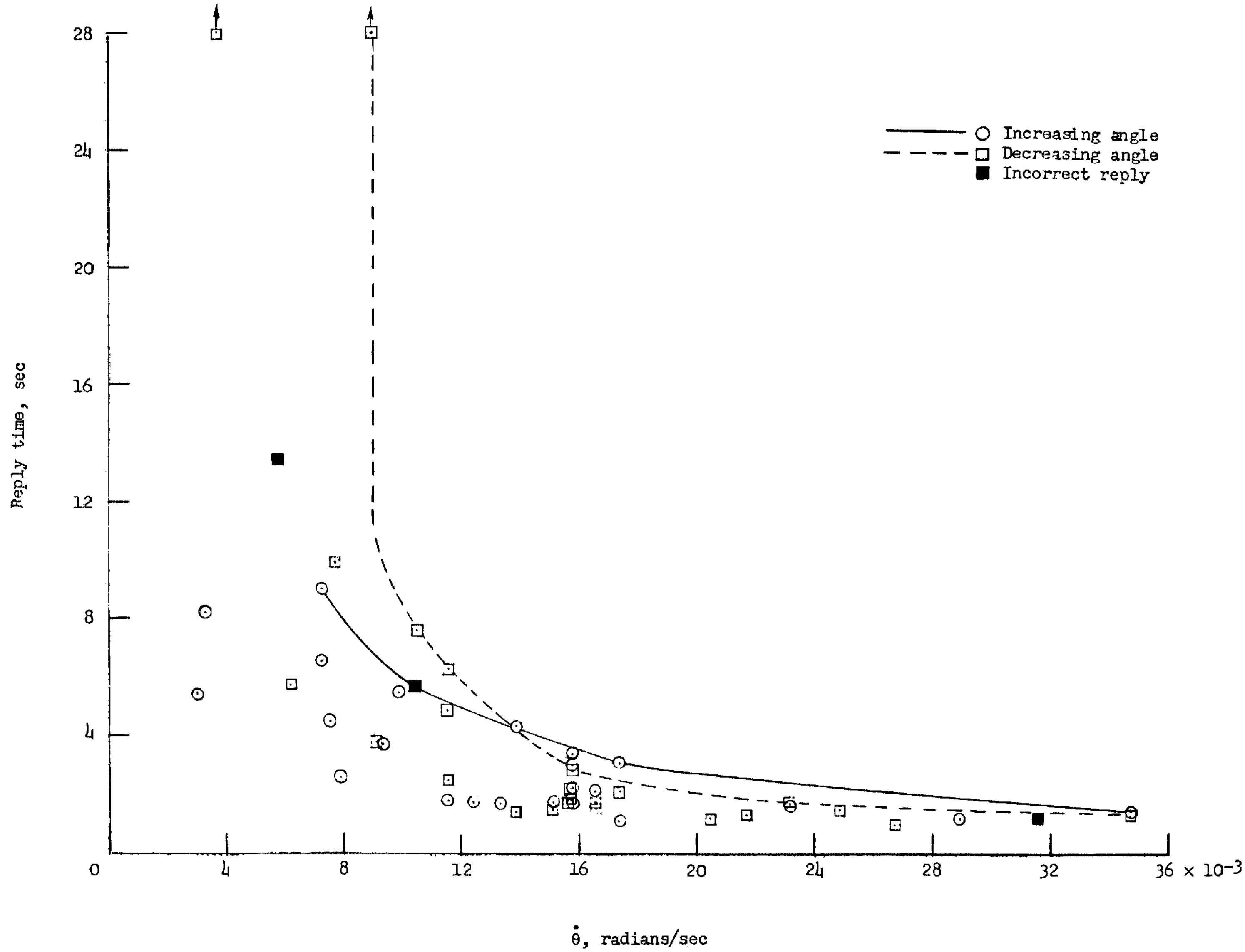
(b) Observer A. $\theta = 41^{\circ}$.

Figure 2.- Continued.



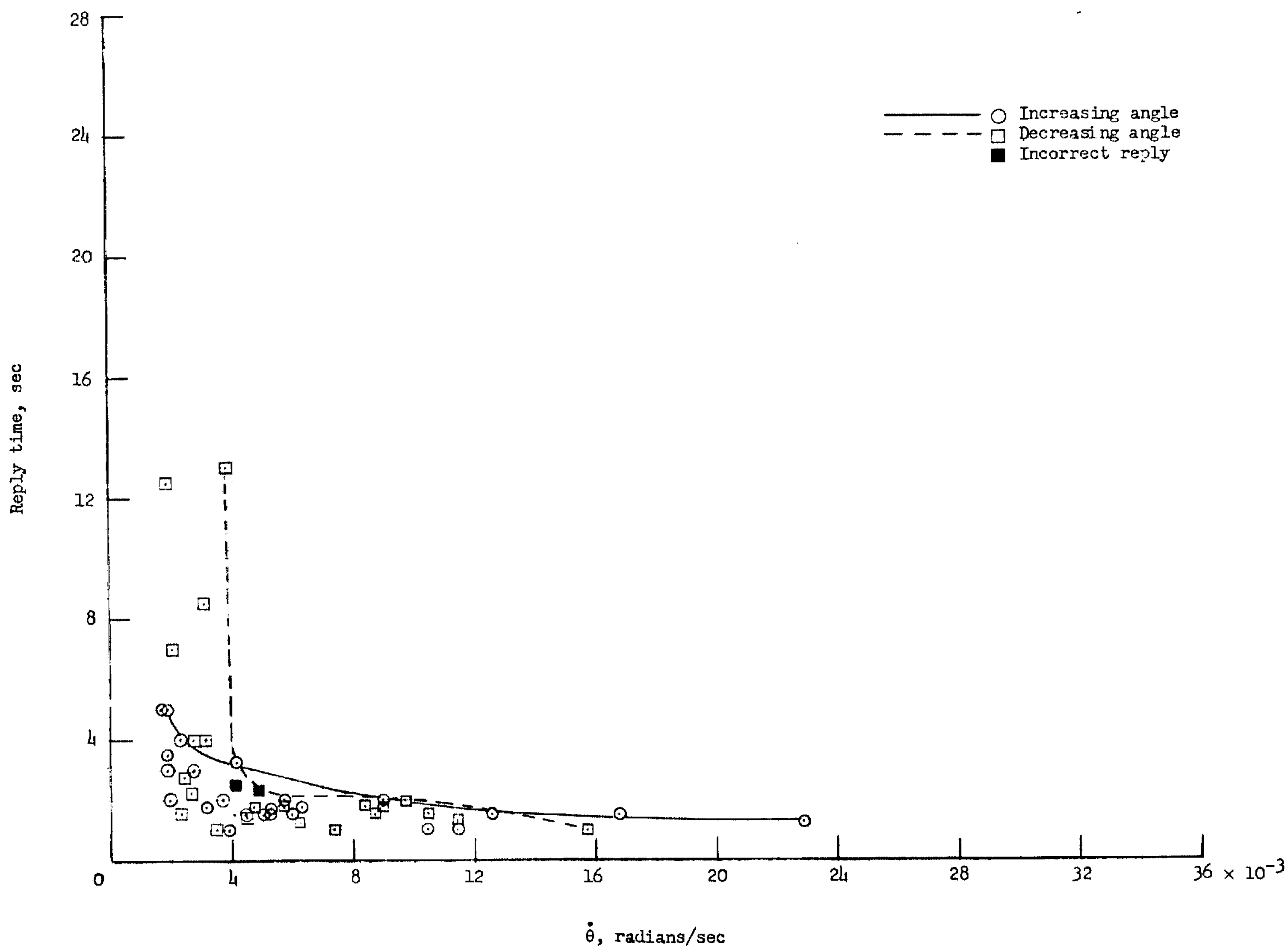
(c) Observer A. $\theta = 68^{\circ}$.

Figure 2.- Continued.



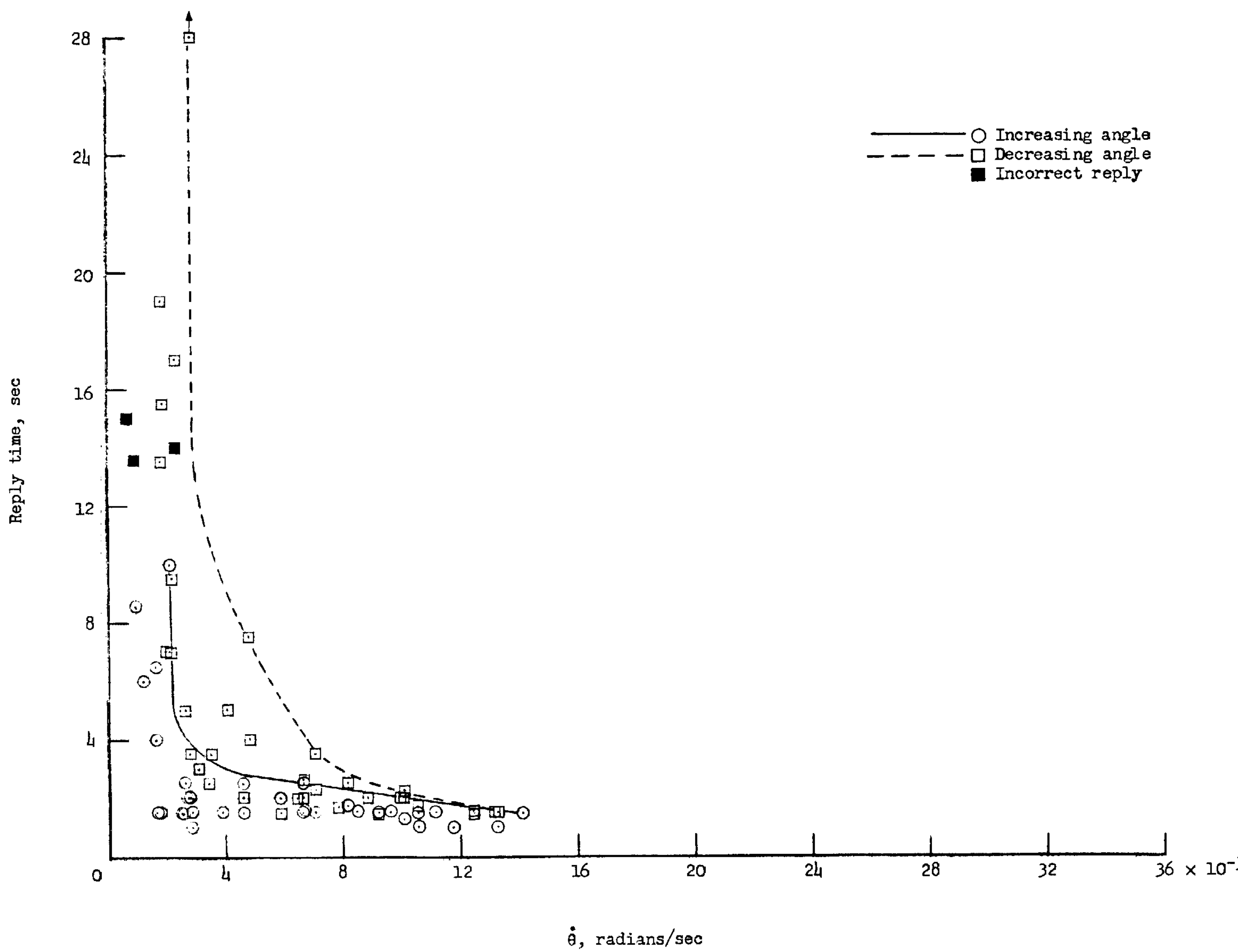
(d) Observer A. $\theta = 128^{\circ}$.

Figure 2.- Continued.



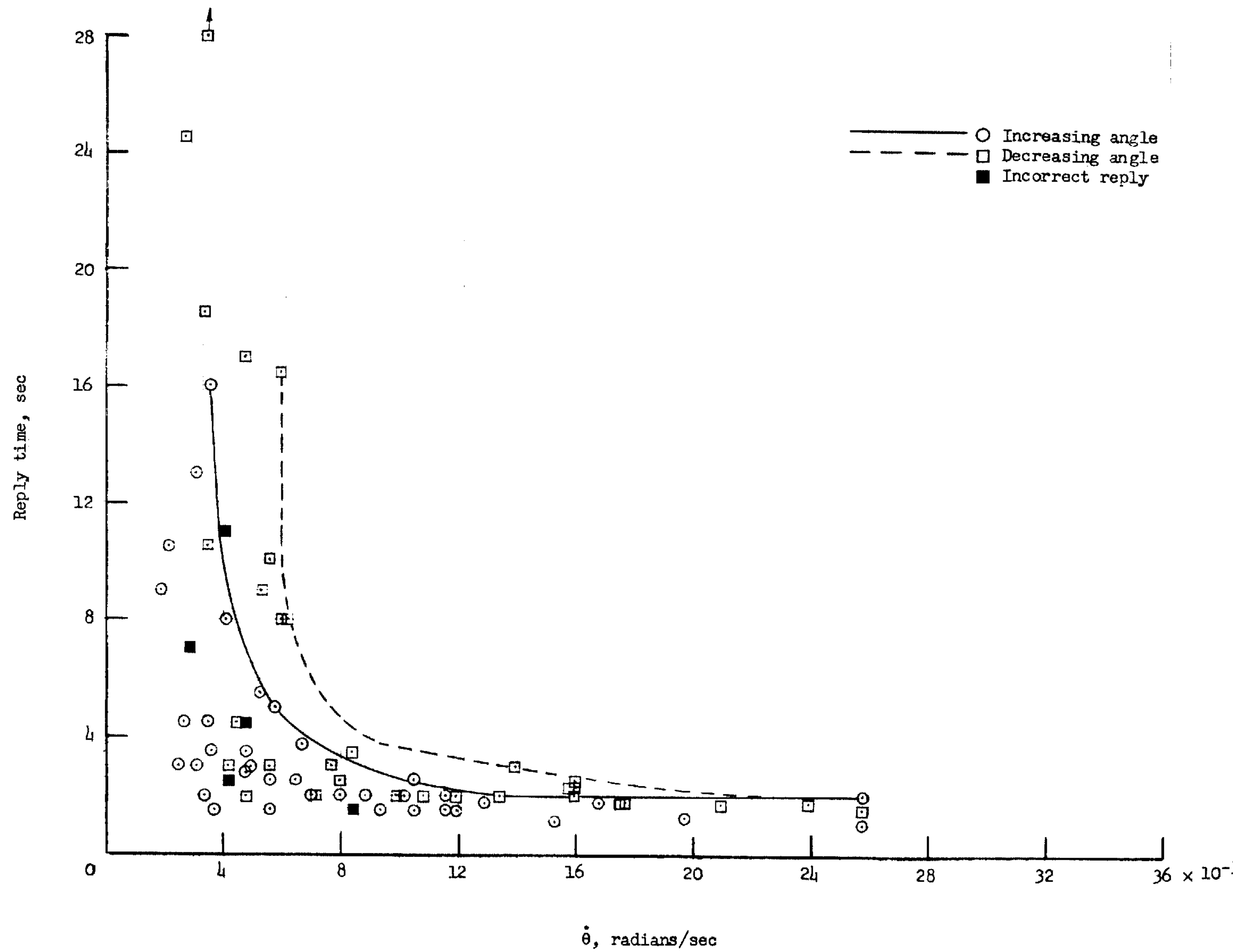
(e) Observer B. $\theta = 11^{\circ}$.

Figure 2.- Continued.



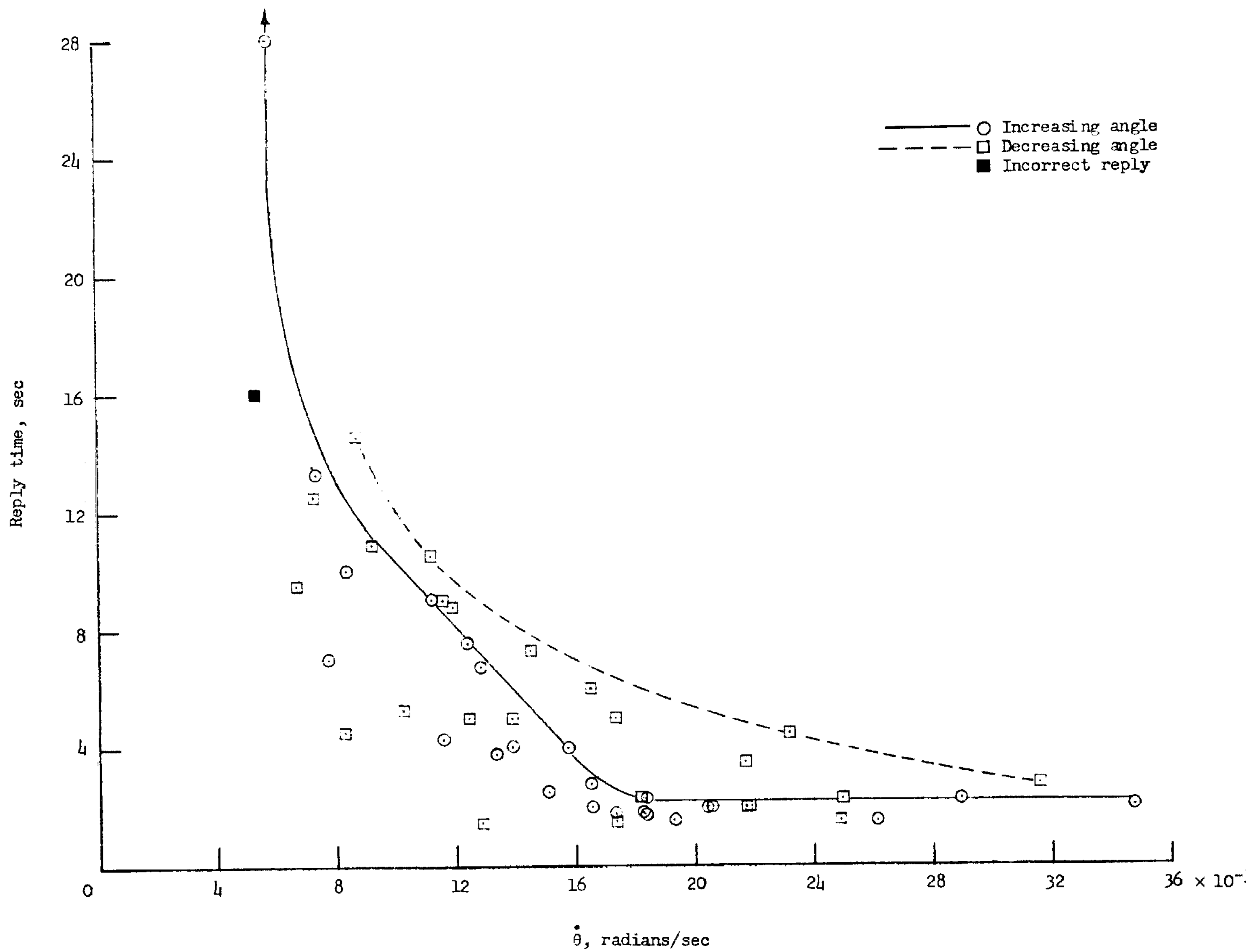
(f) Observer B. $\theta = 41^{\circ}$.

Figure 2.- Continued.



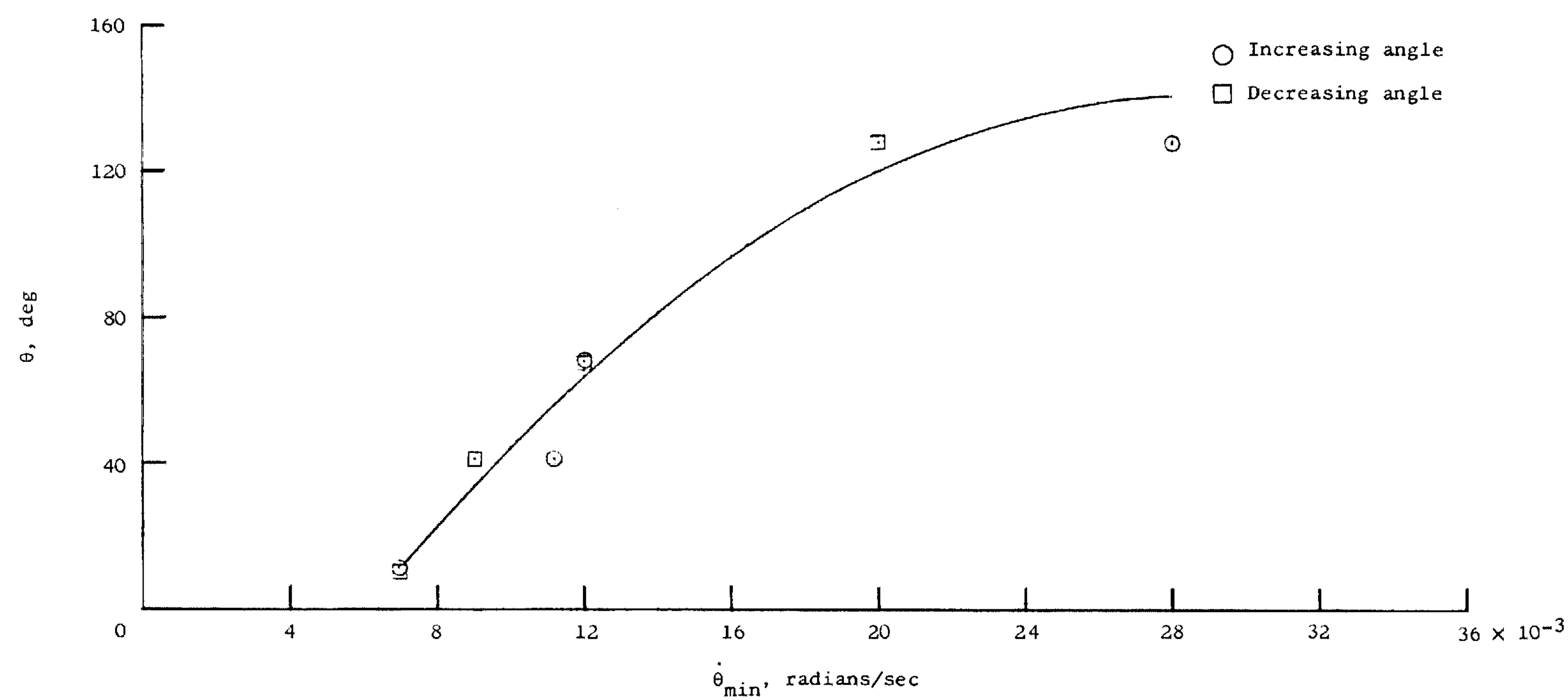
(g) Observer B. $\theta = 68^{\circ}$.

Figure 2.- Continued.



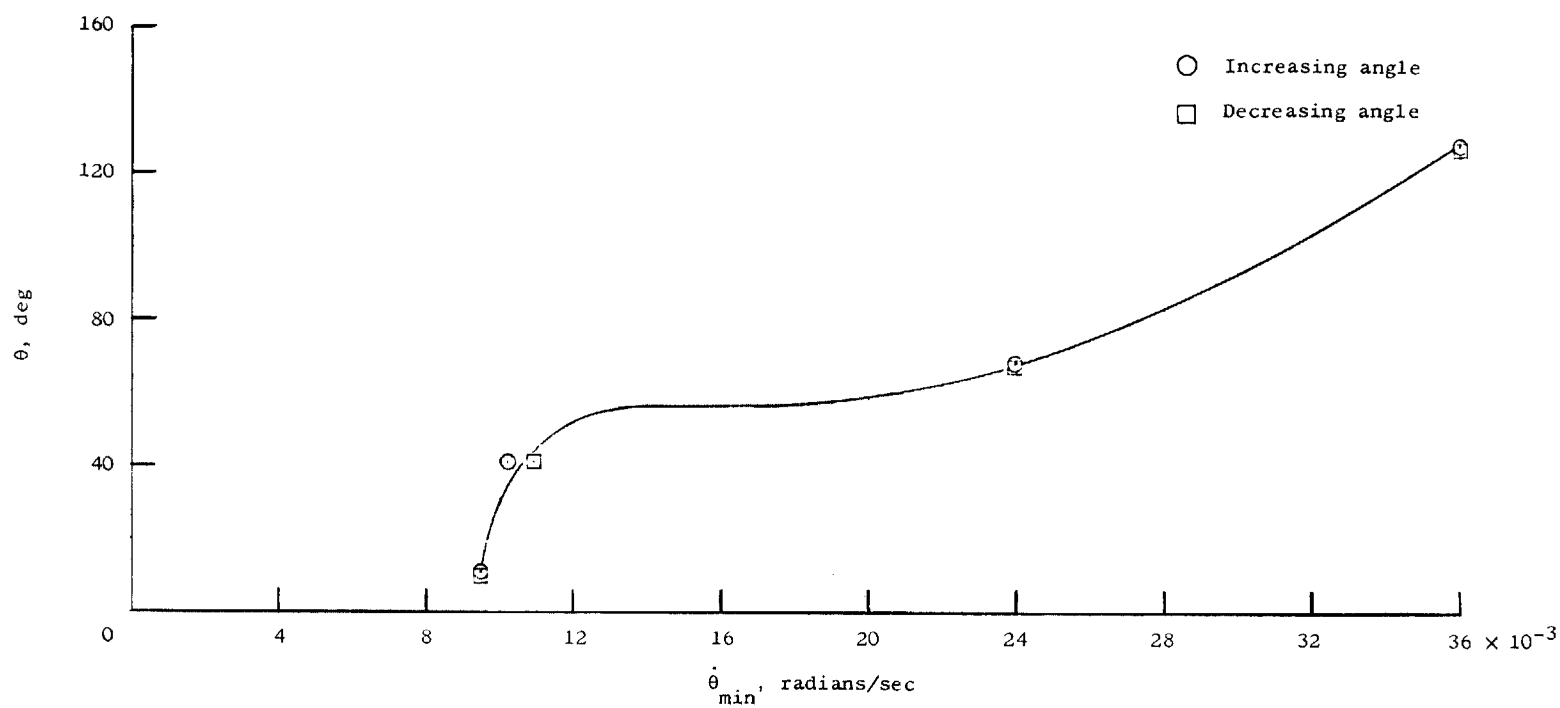
(h) Observer B. $\theta = 128^{\circ}$.

Figure 2.- Concluded.



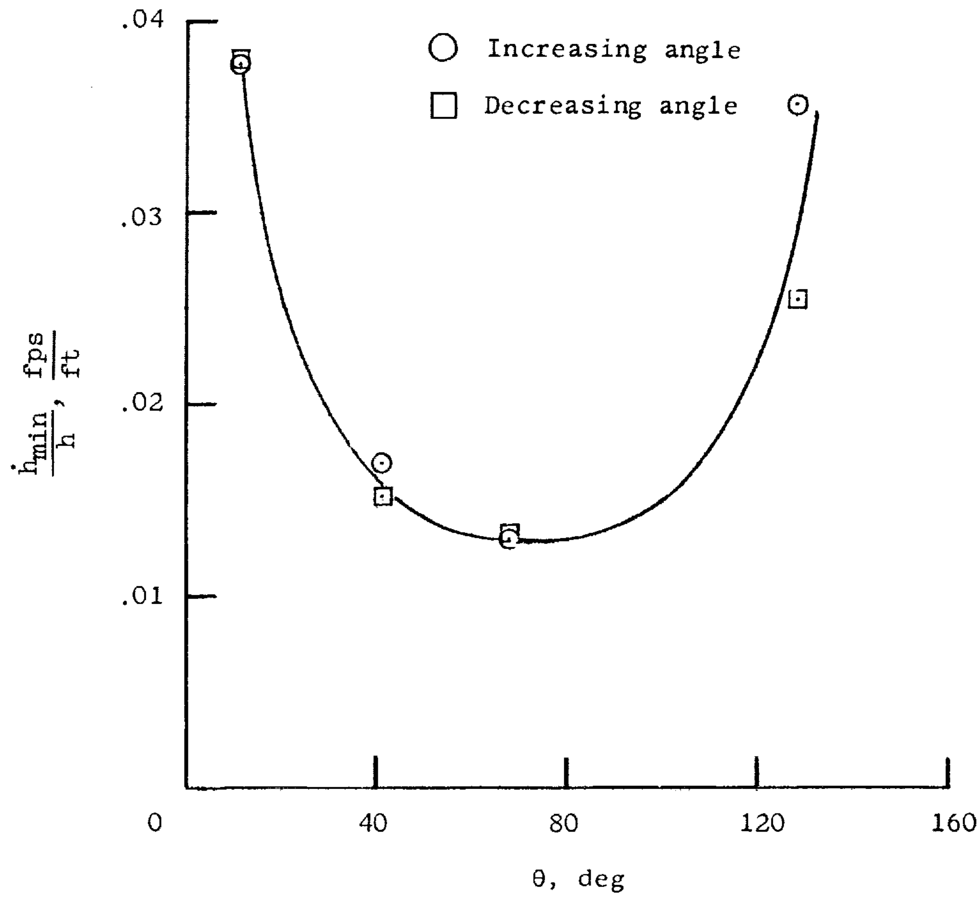
(a) Observer A.

Figure 3.- Variation with visual angle of threshold of perception of angular rate.



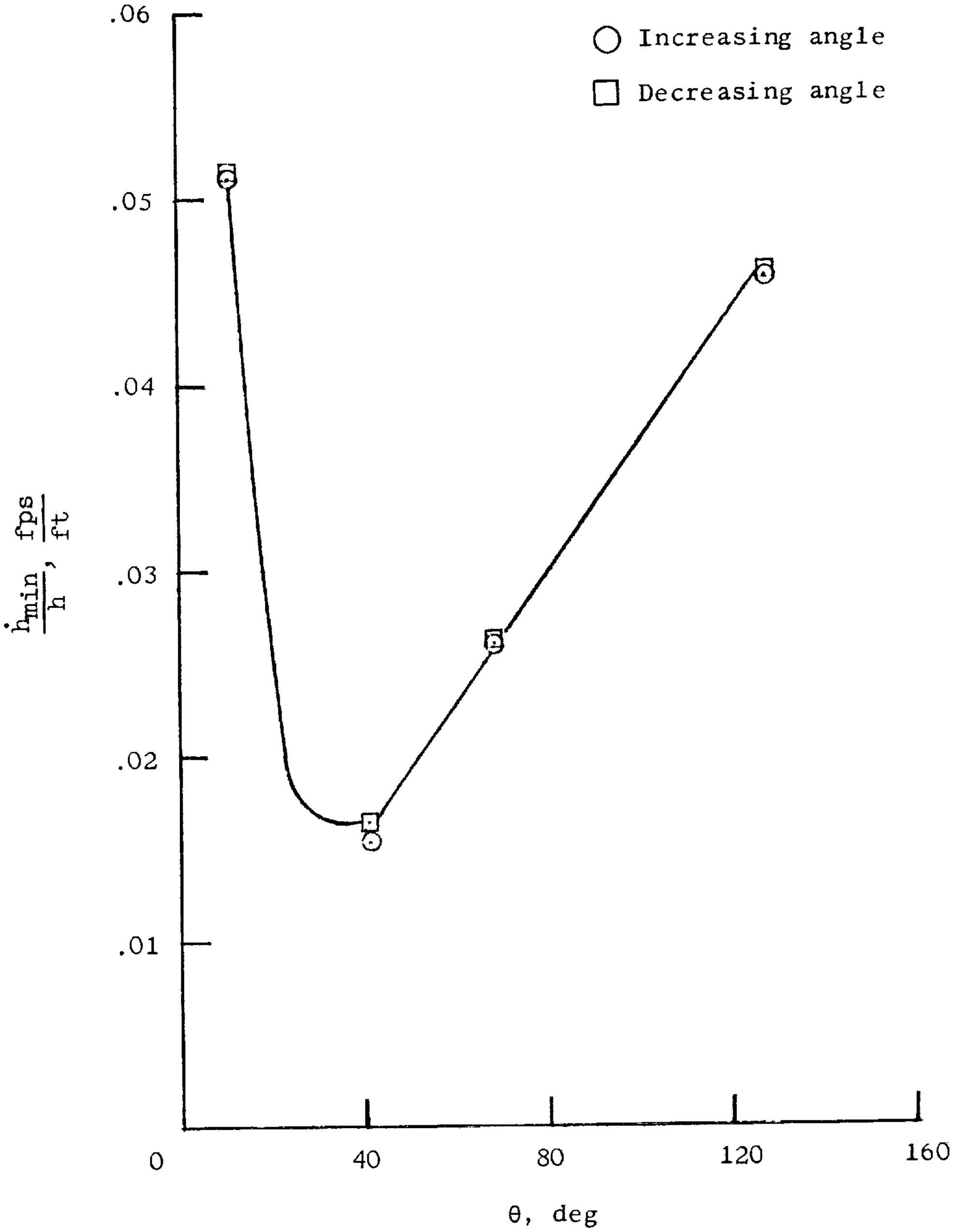
(b) Observer B.

Figure 3.- Concluded.



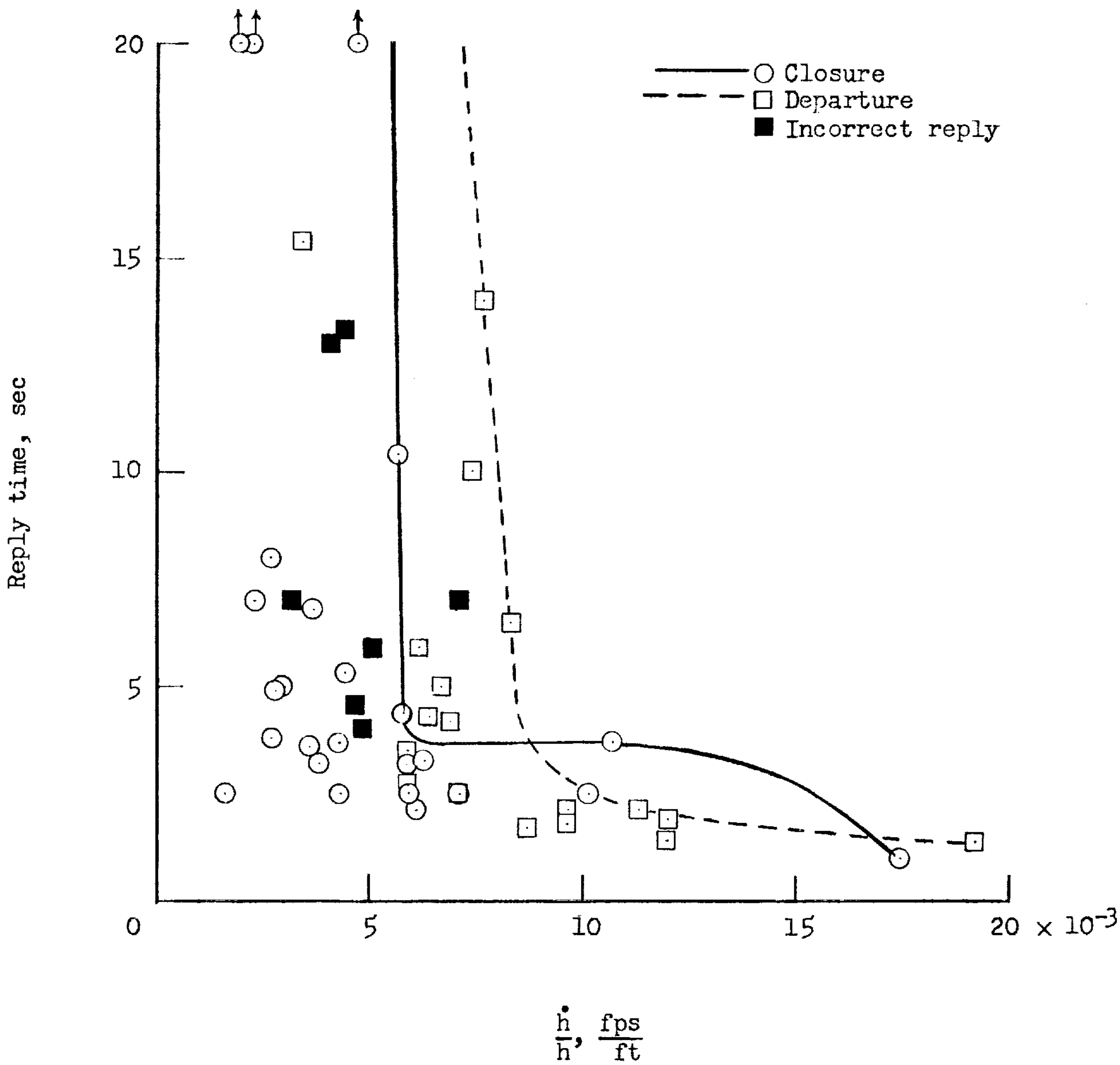
(a) Observer A.

Figure 4.- Variation of velocity perception with visual angle for fixed objects.



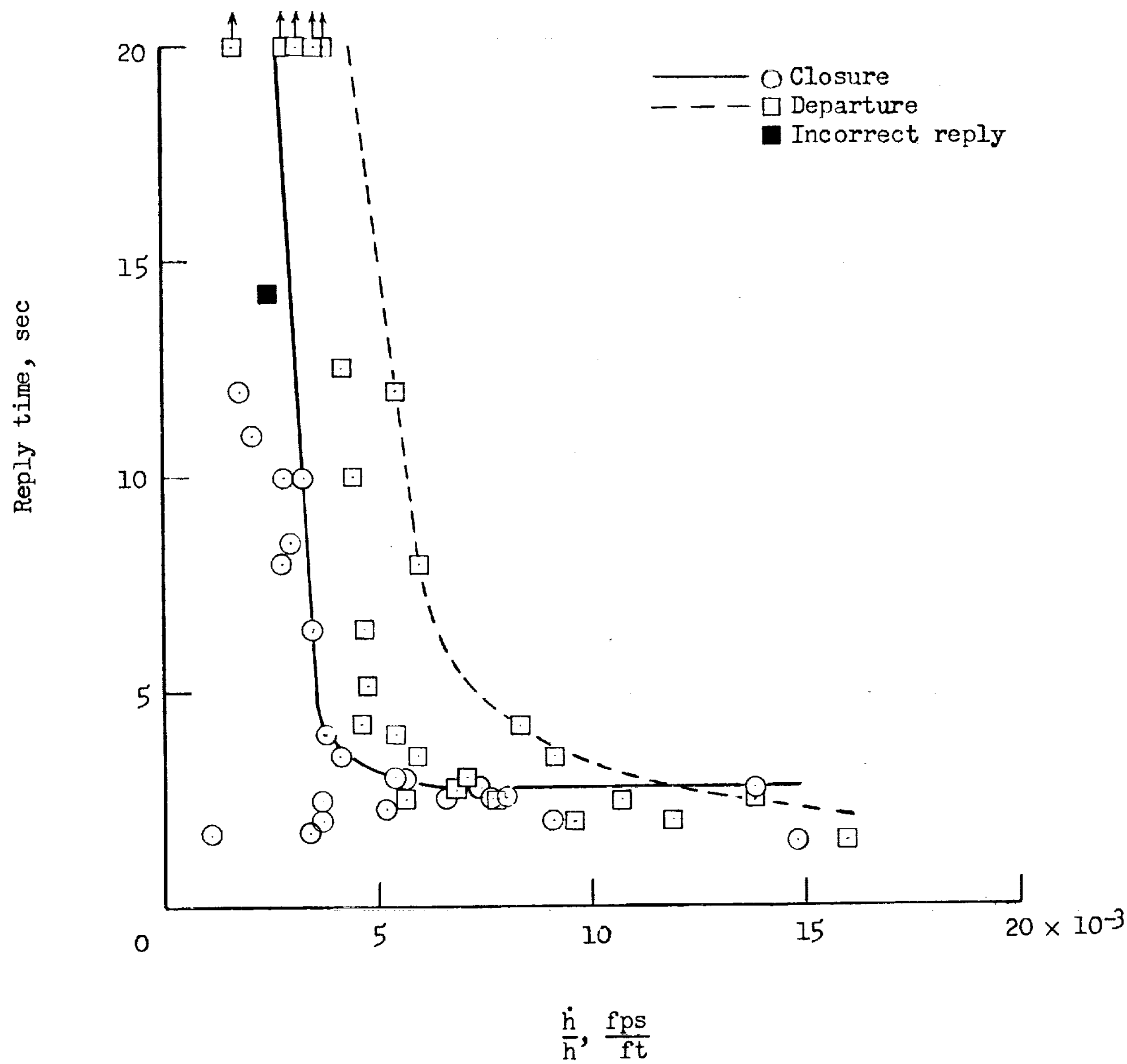
(b) Observer B.

Figure 4.- Concluded.



(a) Observer A.

Figure 5.- Variation of time necessary for decision and reply with change in the ratio of velocity to distance. Curves represent boundaries of reply time that would rarely be exceeded.



(b) Observer B.

Figure 5.- Concluded.

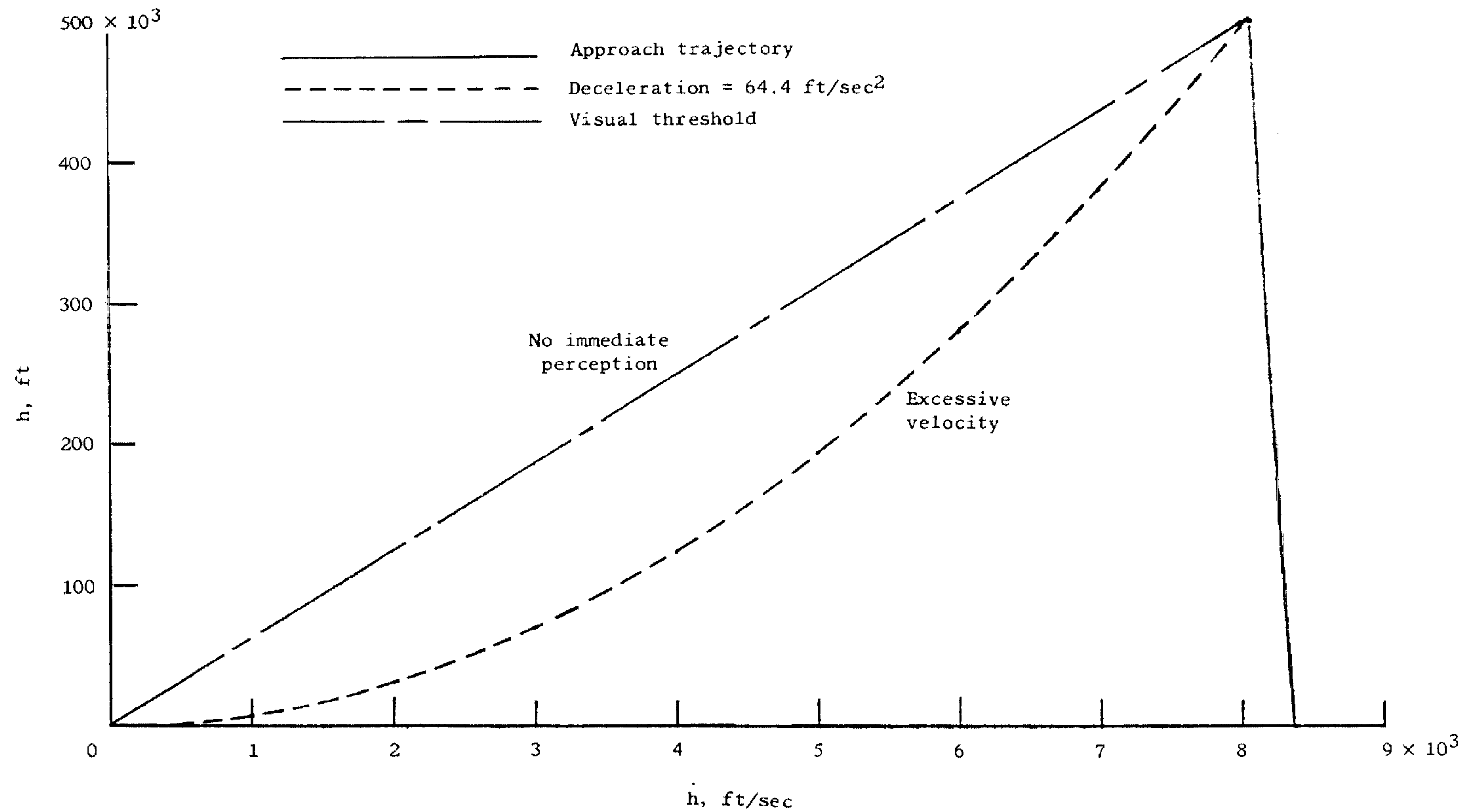


Figure 6.- Range of altitude and speed for human control ability in vertical-approach lunar landing.

NASA-Langley, 1963 L-3141